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LANSCE DIVISION RESEARCH REVIEW

Single-Event-Effects Measurements at the LANSCE Irradiation of Chips and Electronics House

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The Los Alamos Neutron Science Center (LANSCE) Irradiation of Chips and Electronics (ICE) House is located on the 30° left flight path (FP) of the high-energy neutron source at the Weapons Neutron Research Facility (WNR). The shape of the neutron spectrum on this FP is very similar to the spectrum of neutrons produced in the atmosphere by cosmic rays, but with a flux more than 5 orders of magnitude higher (Fig. 1). This large neutron flux allows testing of semiconductor devices at greatly accelerated rates in which one hour of exposure at LANSCE is equivalent to more than 100 years of flight time.

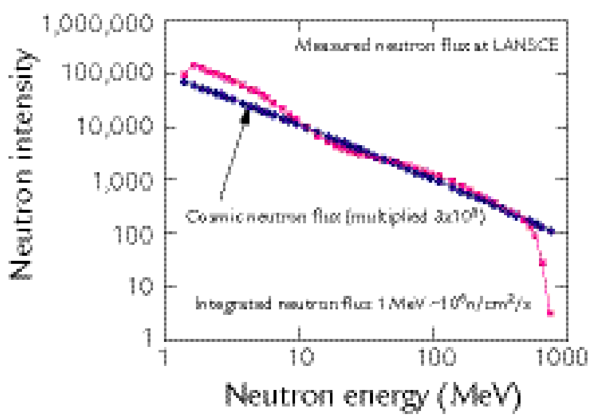

Fig. 1. *The LANSCE neutron spectrum is very similar to the cosmic-ray-induced neutron spectrum but with a flux more than 5 orders of magnitude.*

Testing neutron-induced single-event effects (SEE) is important because neutrons have been recognized as a significant threat to semiconductor devices at aircraft altitudes. Since WNR was first demonstrated as an effective SEE testing tool in 1992, a growing number of companies from around the world continue to use the WNR high-energy-neutron source to study various failure modes caused by neutron radiation. The ultimate goal of this research is to find ways to overcome the effects of incoming galactic- and solar cosmic-ray-induced neutrons.

Effects of Neutrons Produced in Space

Galactic and solar cosmic rays collide with nuclei in the upper atmosphere creating a shower of sub-atomic particles. The charged-particle components of the cosmic-ray shower are strongly absorbed by the atmosphere, but the neutrons are able to reach aircraft altitudes and below because they have no charge. These energetic incoming neutrons penetrate semiconductor devices and collide with the atoms in the material, causing charged recoils (i.e., from neutron and atom collisions) and the production of secondary particles (e.g., protons, electrons) that deposit charge and energy in the devices (Fig. 2). This charge deposition can initiate so-called SEEs in semiconductor devices that can seriously affect their performance.

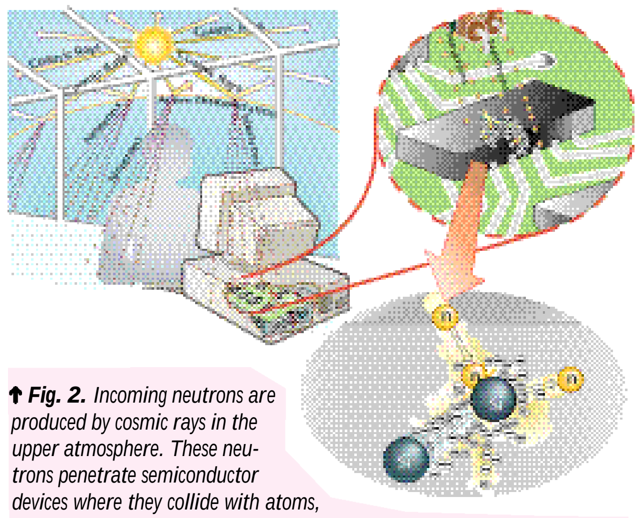

Fig. 2. *Incoming neutrons are produced by cosmic rays in the upper atmosphere. These neutrons penetrate semiconductor devices where they collide with atoms, causing recoils that deposit charge and thus initiating SEEs.*

SEEs include single-event upsets (SEUs), multiple-event upsets (MEUs), single-event latchup, single-event burnout, and gate rupture. SEUs occur when a memory location changes its state because of charge deposited by an energetic particle. SEUs typically occur at a rate of approximately one upset per billion bits per hour at aircraft altitudes. Although this type of failure may be corrected by error checking, increased costs and a loss of performance are associated with this solution. MEUs, where several memory locations are altered, have been measured to be a few percent of the single-event rate. MEU failures are more difficult to correct than SEUs. Failures such as latchup in which a device ceases to function are more serious because they usually require turning the device off and then on to eliminate the latchup. Other more serious failure modes occur in high-power devices in which a neutron can initiate a cascade of charged particles that causes these devices to draw large currents—possibly permanently damaging them as a result. The failure rate in these devices strongly depends on the amount of applied voltage. The failure rate increases dramatically above a critical threshold voltage that may be significantly less than the rated voltage of the device.

Advantages of Testing in the ICE House

The ICE House provides experimenters with several advantages over other testing methods. Unlike heavy-ion tests where a device must have its case material removed and placed in vacuum to permit particles to reach the sensitive regions of the chip, testing in the ICE House beam permits normal operation of the device in the open air. In fact, because neutrons are not strongly absorbed by the device, several devices may be placed in the neutron beam at once, one behind the other.

The integrated neutron flux at the ICE House is approximately 10^6 neutrons/cm^2/s for energies above 1 MeV. No other facility in the world can offer this intensity with a spectrum matching the natural atmospheric spectrum so closely. Because this flux is achieved with approximately 35,000 individual neutron pulses due to the time structure of the accelerator proton beam, the results are still representative of atmospheric results because the probability of multiple neutron events is exceedingly low for individual pulses with so few neutrons.

Research Conducted During 2001

Listed below with some of their research goals are some of the organizations that used the ICE House beam in the 2001 run cycle.

- **Aerospatiale Aeronautique.** Validating and characterizing (1) new avionics systems using synchronous dynamic random-access memory protected by error detection and correction and (2) 0.6-µm and 0.25-µm static random-access memory (SRAM) to confirm a new theoretical model.
- **Altera Corporation.** Testing several new programmable logic devices for neutron-soft-error sensitivity.
- **Honeywell.** Determining failure rates of several types of fielded SRAM, comparing failure rates to past field history, and studying SEE in programmable-logic-device (PLD) circuits.
- **Infineon Technologies.** Developing memory-module testing techniques.
- **Intel Corporation.** Evaluating various designs of microprocessor circuitry for their sensitivity to high-energy neutrons and of soft-error-rate modeling for the latest products and processing technologies.
- **LSI Logic Corporation.** Evaluating the interplay between critical charge, sensitive volume for static storage nodes, and the associated neutron-soft-error cross section for 0.18-µm complementary-metal-oxide-semiconductor SRAM and PLD circuits.
- **Prairie View A&M University.** Studying items such as SRAM, carbon-nanotube materials, metal-oxide-semiconductor transistors, metal hydride shielding, and spacesuit fabric.
- **Sandia National Laboratories, Lucent Technologies, and Bell Laboratories.** Characterizing neutron-induced SEU in advanced Lucent memory and logic technologies, performing modeling to identify design or process fixes, and investigating upset trends in three integrated circuits of decreasing feature size.

Recent Trends in Neutron-induced SEE Research

In addition to continuing research efforts into traditional memory upsets, new issues emerged from recent work. Effects on logic nodes in field-programmable gate arrays are being widely studied. The relationship between failure rates and feature size is hotly debated. Where some experimenters had predicted the SEE problem to worsen with decreased size, failure rates have remained relatively constant or even decreased. However, some mitigation methods have not shown the predicted improvements. Over all, predictions from computer codes have become unreliable. Clearly, either something new is taking place in the chips or traditional analysis is no longer appropriate. Research opportunities in the field are abundant at this time.

Developing a Los Alamos National Laboratory SEE Research Program

LANSCE believes there is an opportunity to grow our research participation in SEE. An ICE workshop was held in July 2001 to discuss LANL capabilities and interests and to consider paths for growth. LANSCE is aggressively seeking collaborators in this development effort. Sandia National Laboratories, the National Aeronautics and Space Administration, and the Federal Aviation Administration have all expressed interest in exploring a significant research facility based on the LANSCE WNR neutron beam. LANSCE is also exploring the idea of participating on electronics standards committees such as the Joint Electron Device Engineering Council, which has drafted a testing/performance standard for neutron-induced SEE.

Summary

Neutron-induced SEEs are again emerging as a significant threat to semiconductor electronics. LANSCE, through the new ICE House, is uniquely positioned to address this problem for the electronics industry and the nation. Valuable research at the forefront of the field is being conducted at the LANSCE ICE House where new research opportunities are being uncovered. LANSCE is aggressively pursuing collaborators to develop a SEE research program at Los Alamos National Laboratory.

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Los Alamos NATIONAL LABORATORY

LANSCE Los Alamos Neutron Science Center

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